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Sumita

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(54) **ELECTROLYTIC CELL FOR PRODUCING CHARGED ANODE WATER SUITABLE FOR SURFACE CLEANING OR TREATMENT, AND METHOD FOR PRODUCING THE SAME AND USE OF THE SAME**

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(57) **ABSTRACT**

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See application file for complete search history.

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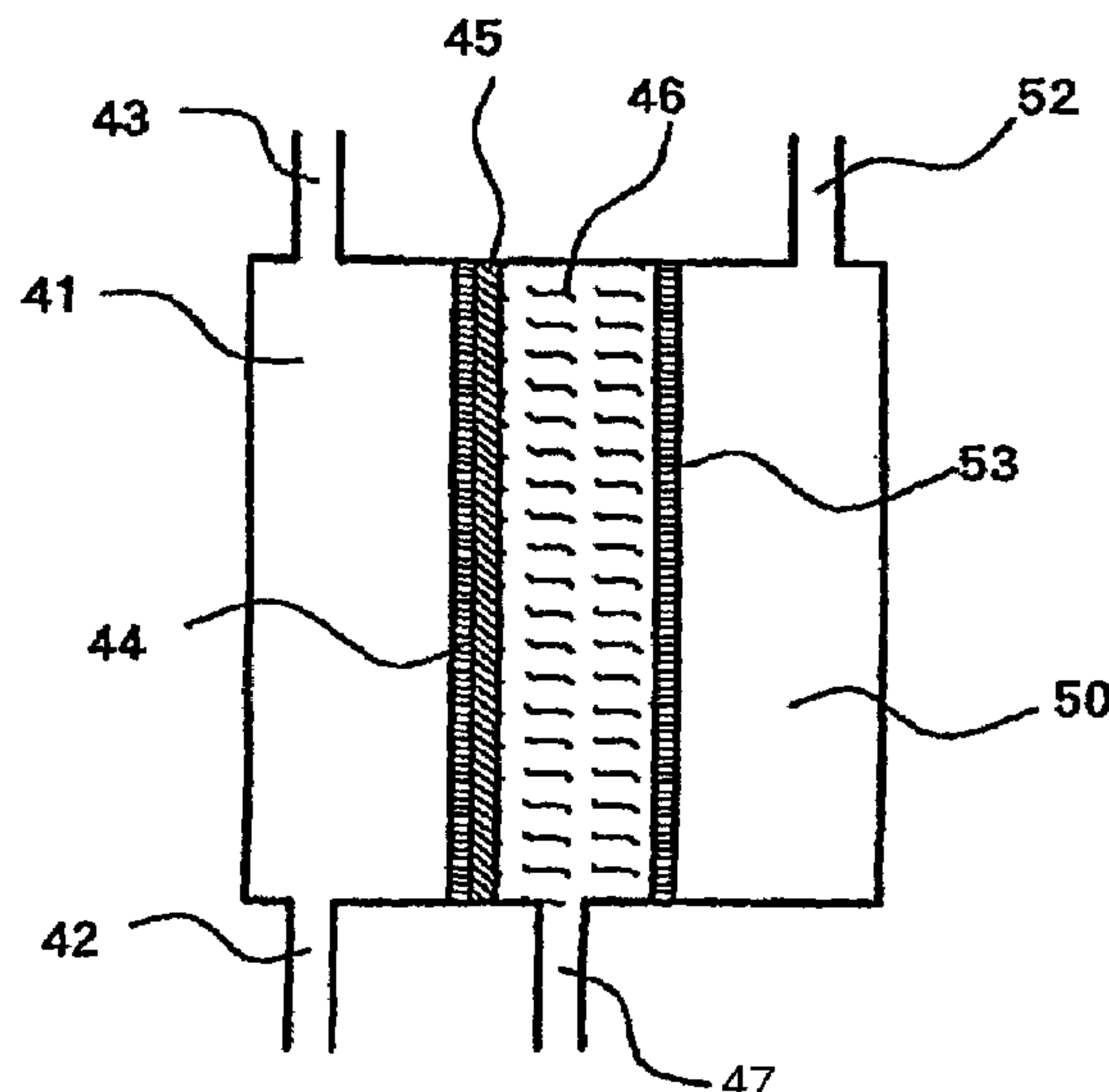
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The present invention provides an electrolytic cell, which can efficiently produce charged water having an excellent performance of improving surface cleaning or treatment of an object, e.g., semiconductor, glass, or resin and of cleaning and sterilizing medical device.

The electrolytic cell of the present invention is for producing charged anode water suitable for surface cleaning or treatment, including the cathode chamber 41 and anode chamber 50, fluorinated cation-exchange membrane 46 provided to separate these chambers from each other, cathode 44 closely attach to the cation-exchange membrane 45 on the side facing the cathode chamber 41, and middle chamber 48 filled with the cation-exchange resin 46, provided on the other side of the cation-exchange membrane 46, the cation-exchange resin 46 being arranged in such a way to come into contact with the fluorinated cation-exchange membrane 45, wherein the feed water is passed into the middle chamber 48 and passed thorough the anode chamber 50 to be recovered as the charged anode water.

15 Claims, 14 Drawing Sheets

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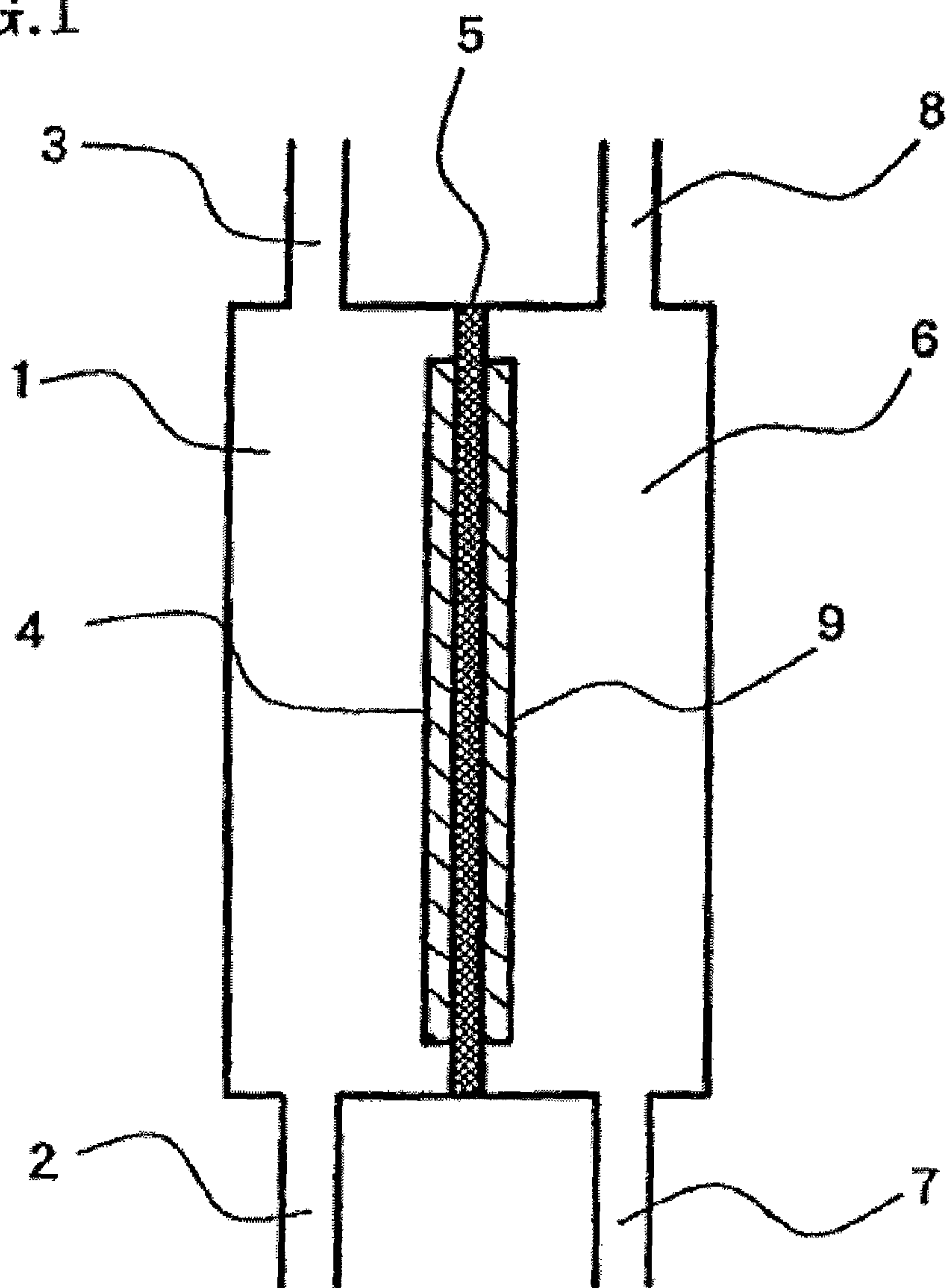
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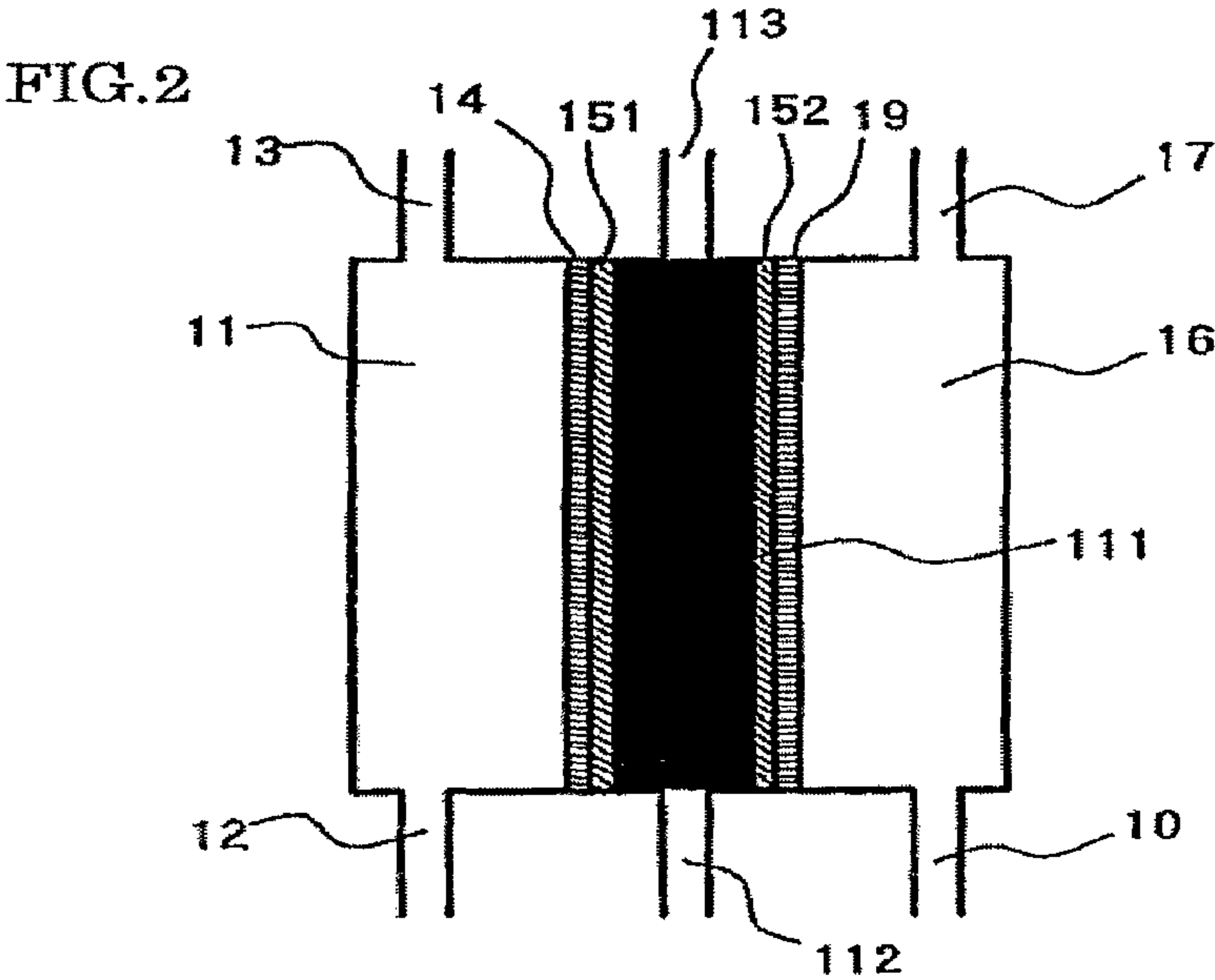
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FIG. 1



PRIOR ART



PRIOR ART

FIG.3

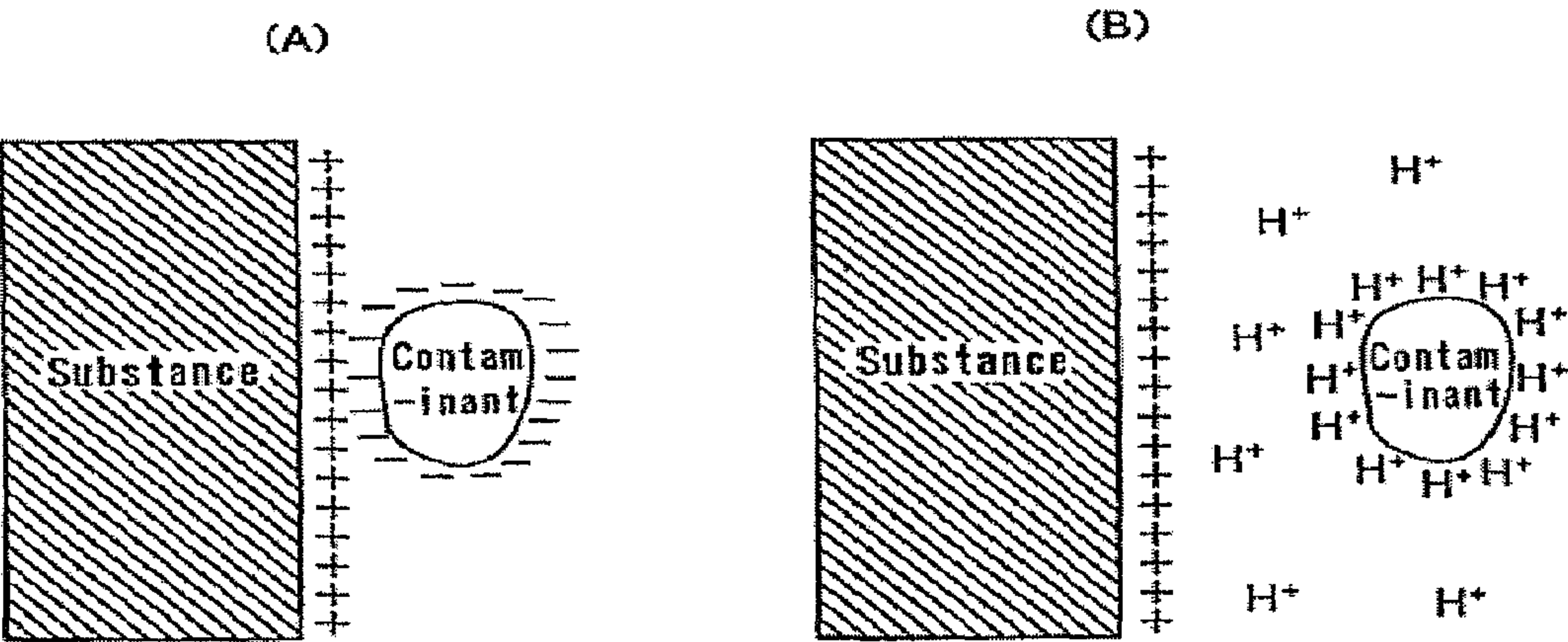


FIG. 4

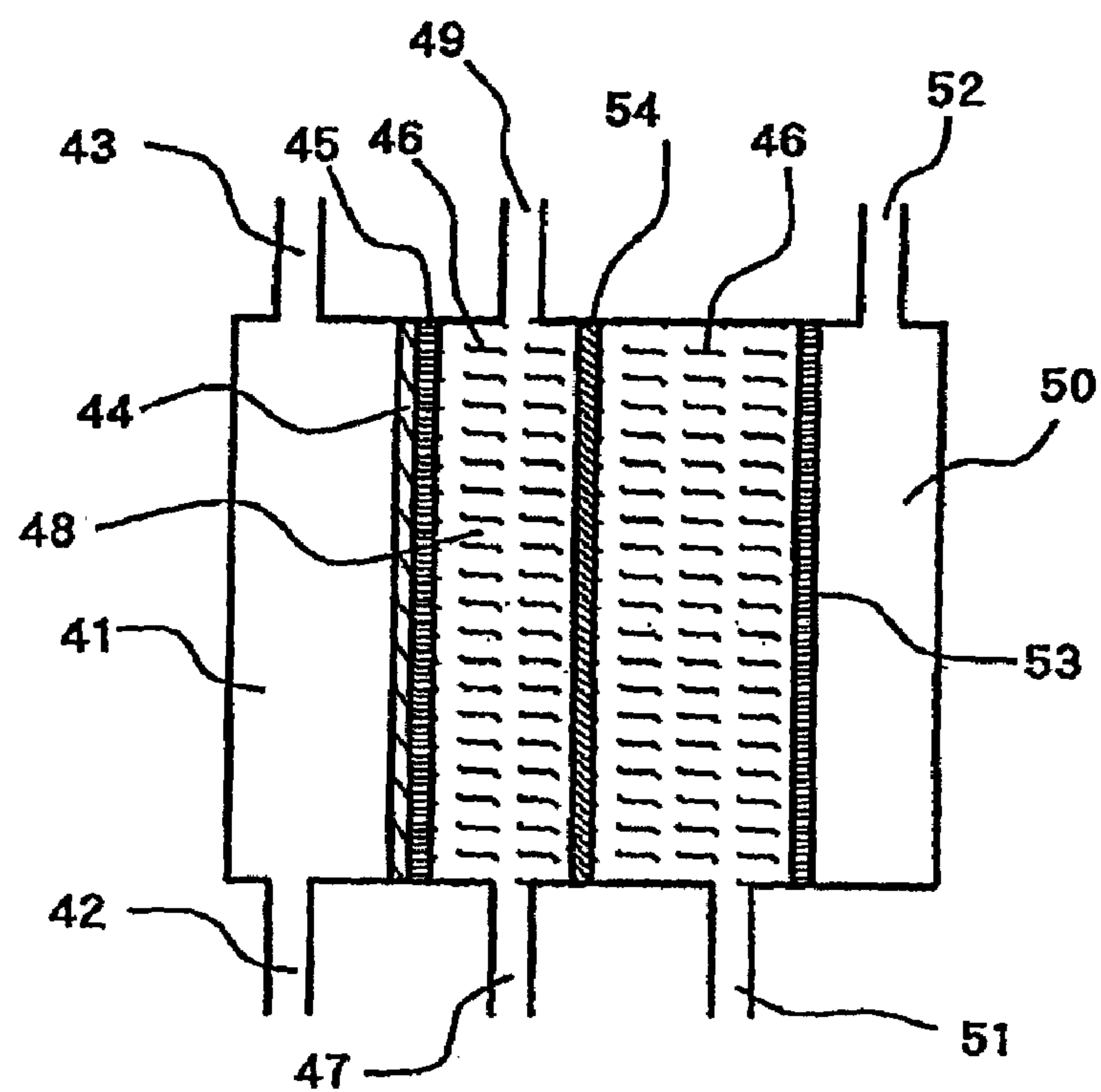


FIG. 5

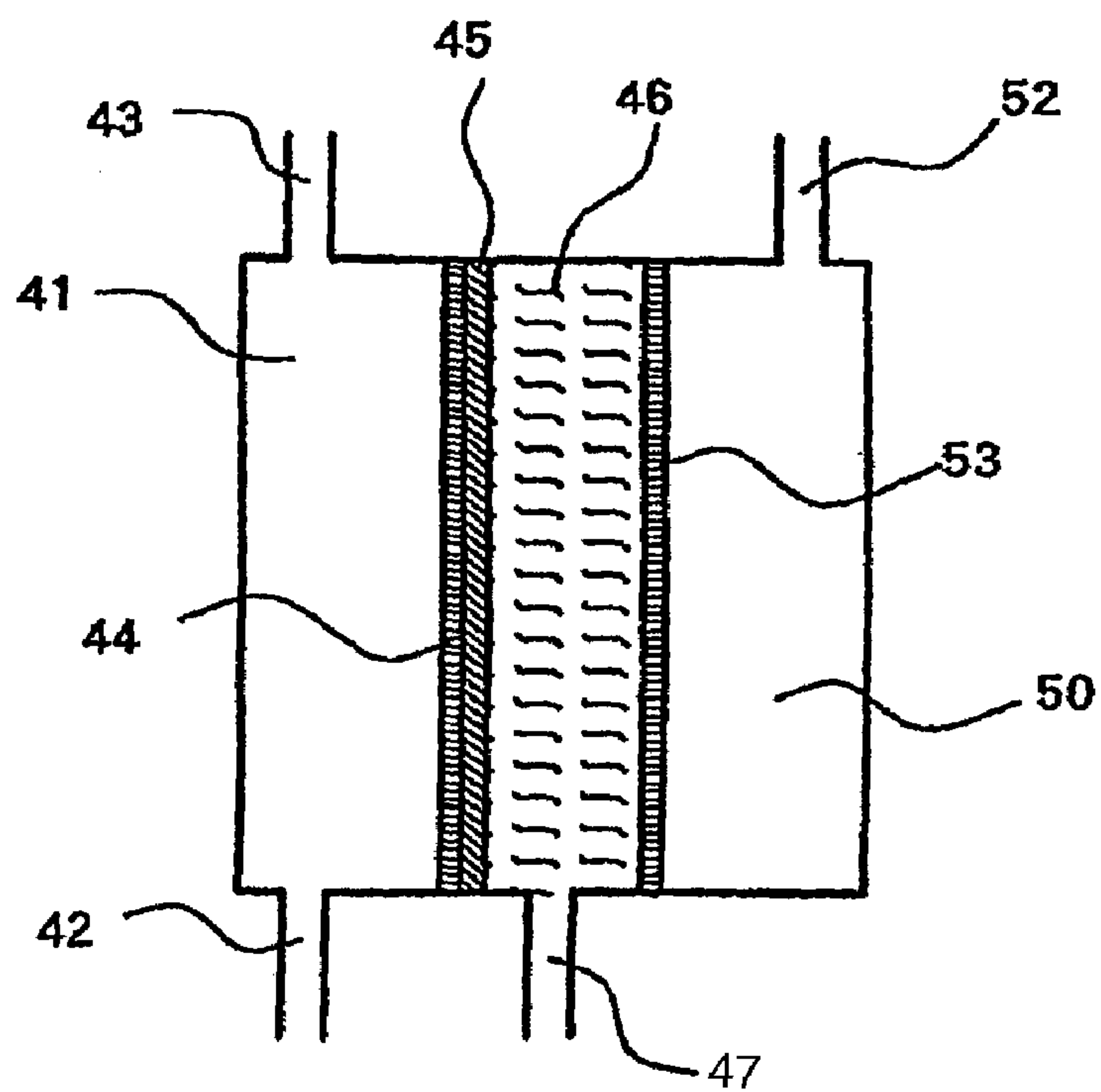


FIG. 6

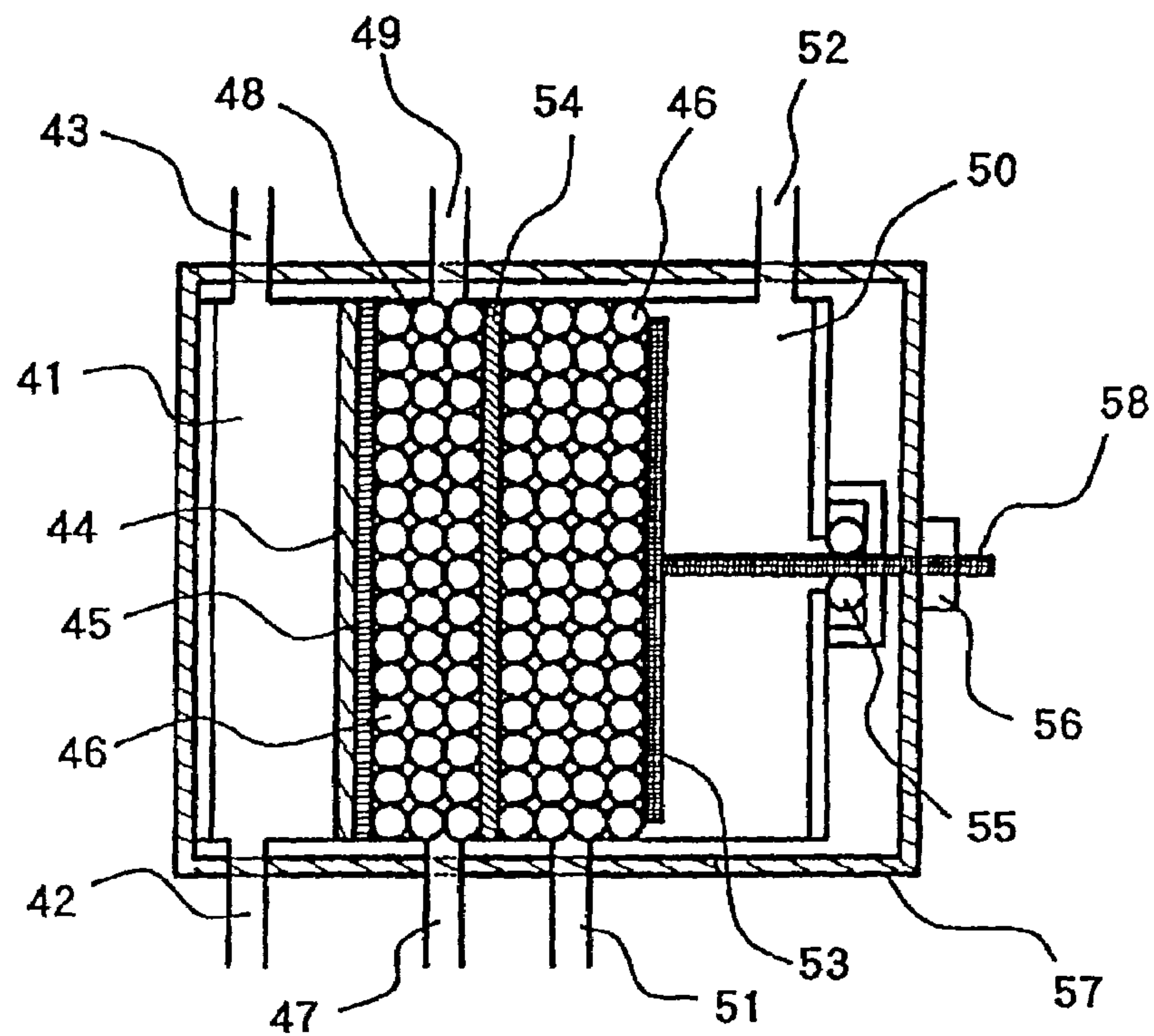


FIG. 7

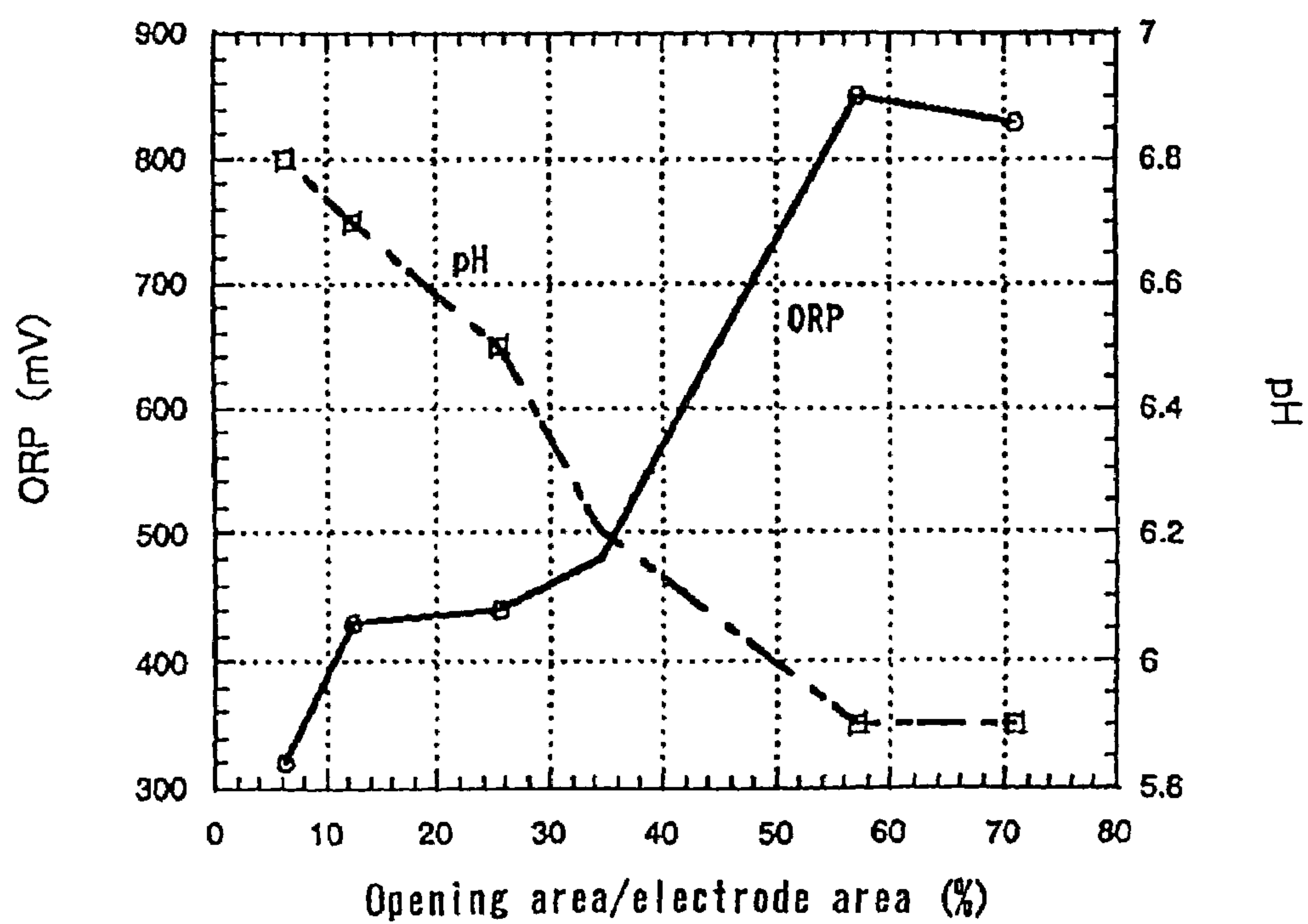


FIG.8

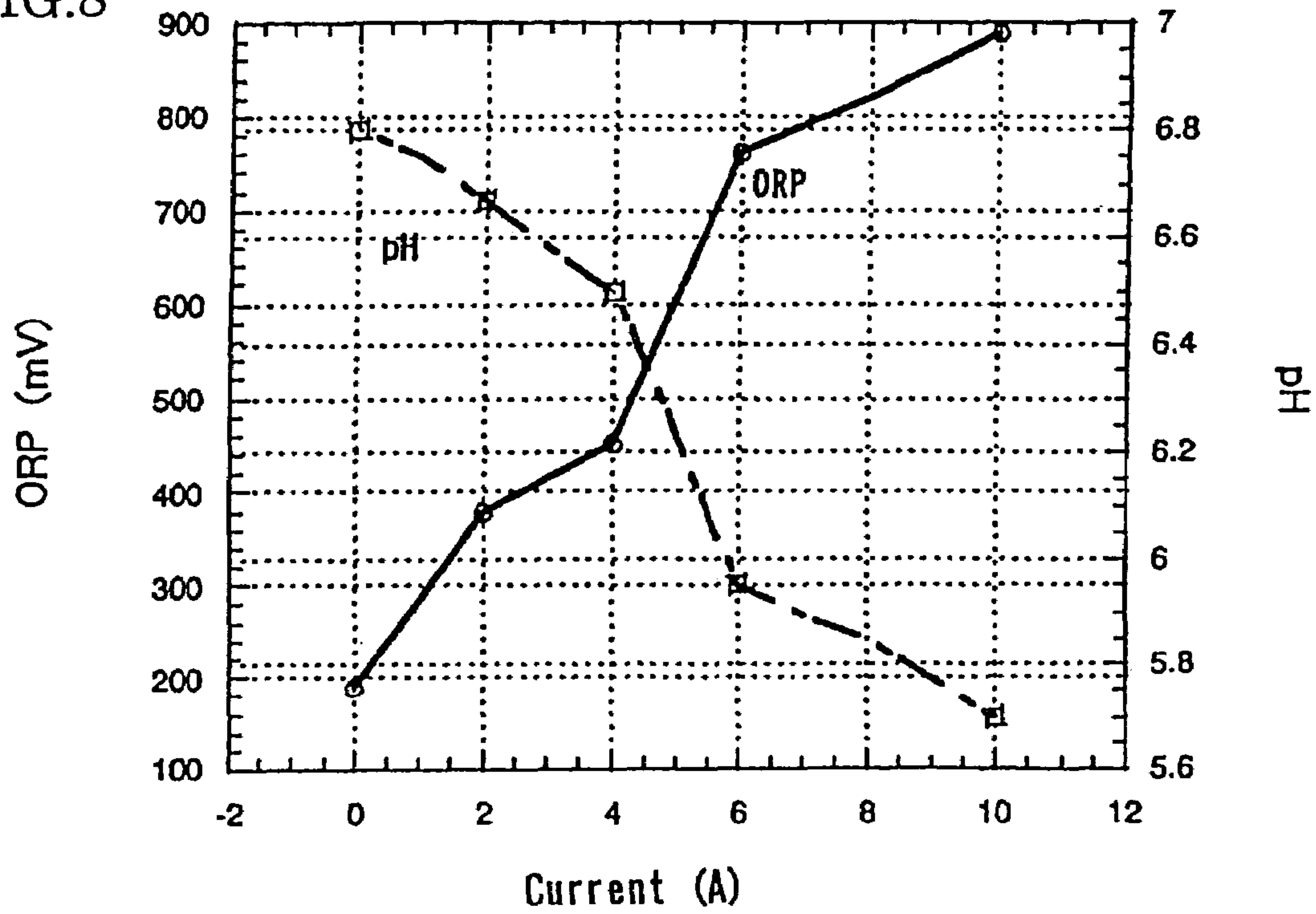
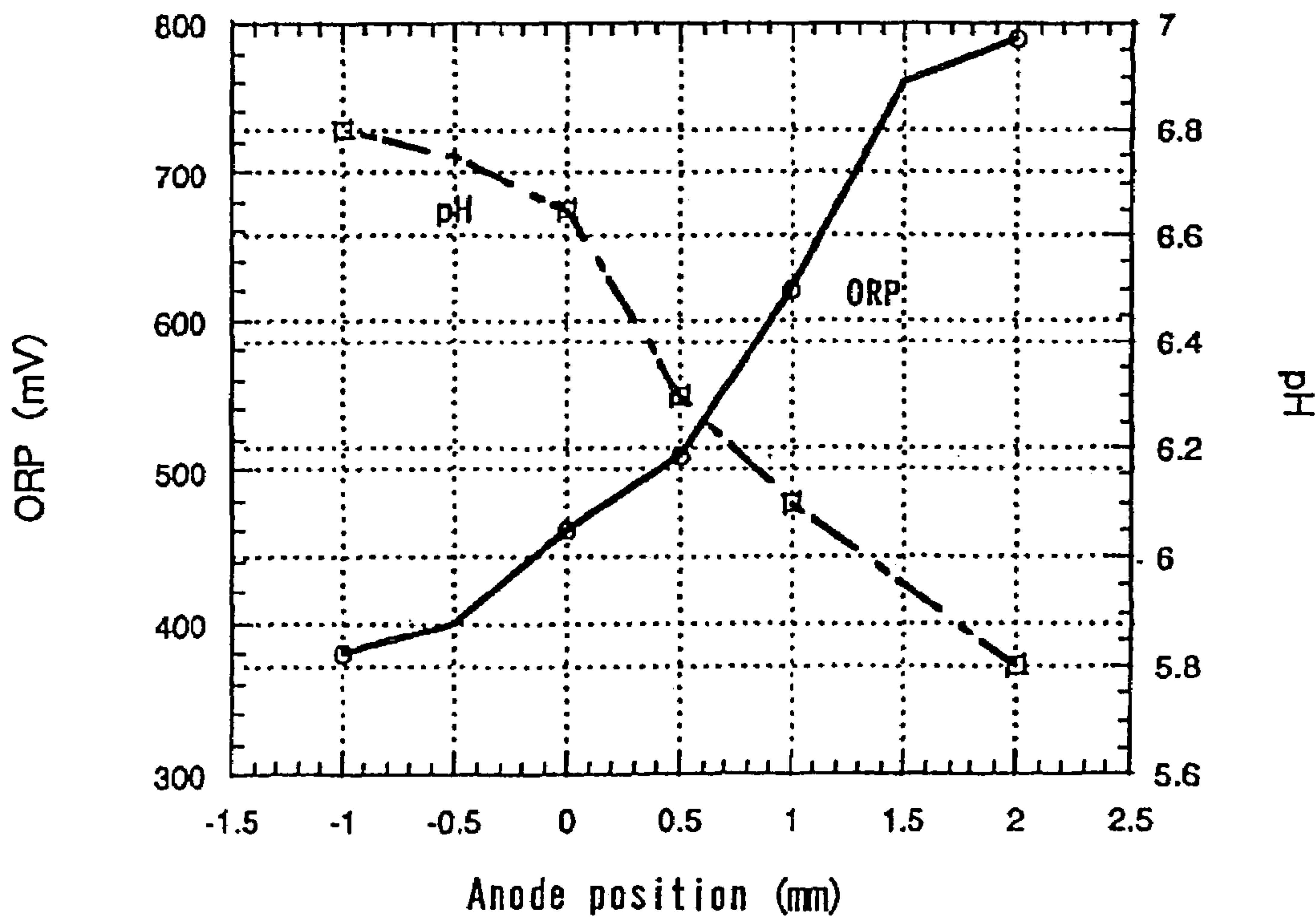


FIG.9



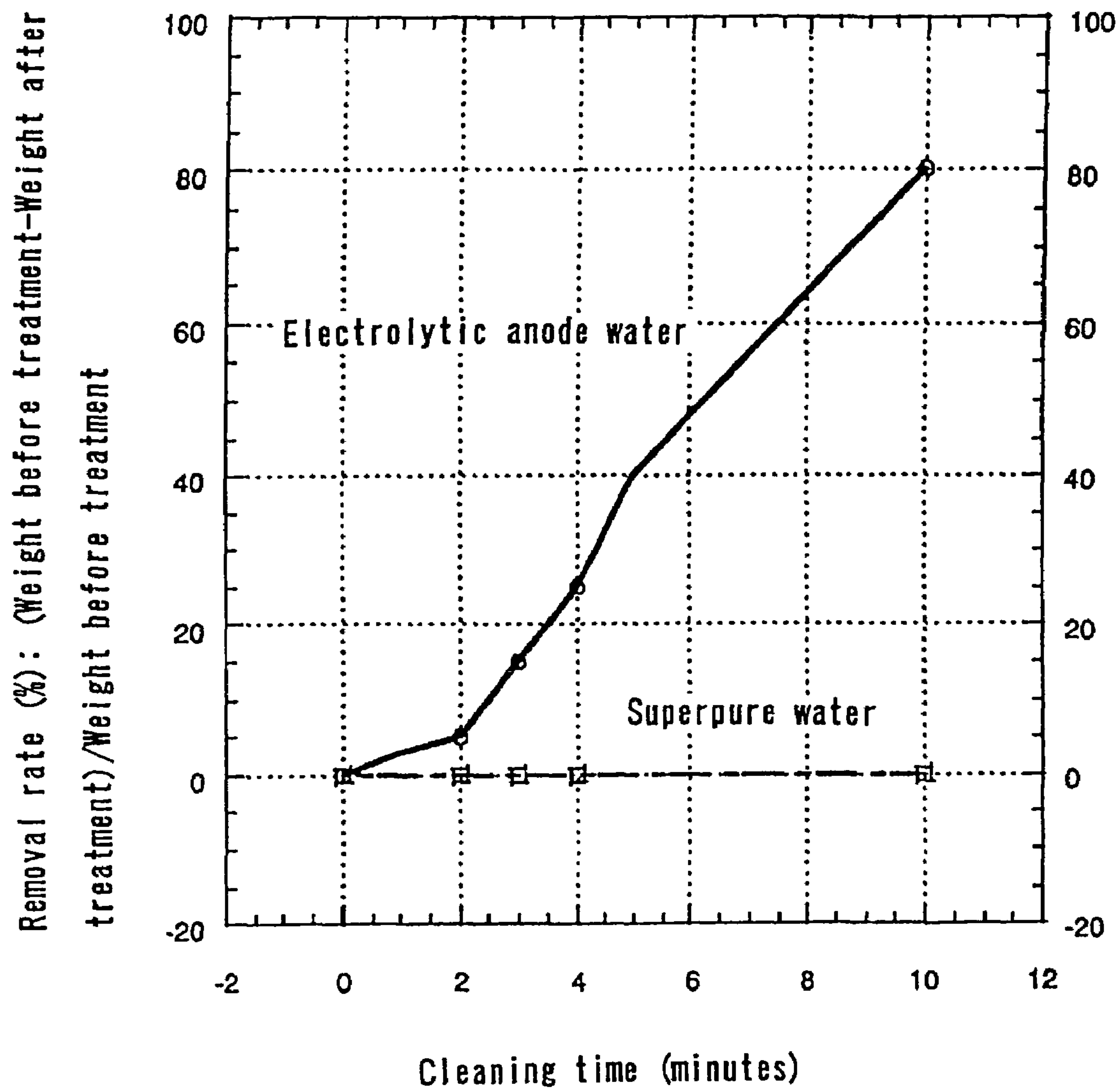


FIG.10

FIG.11

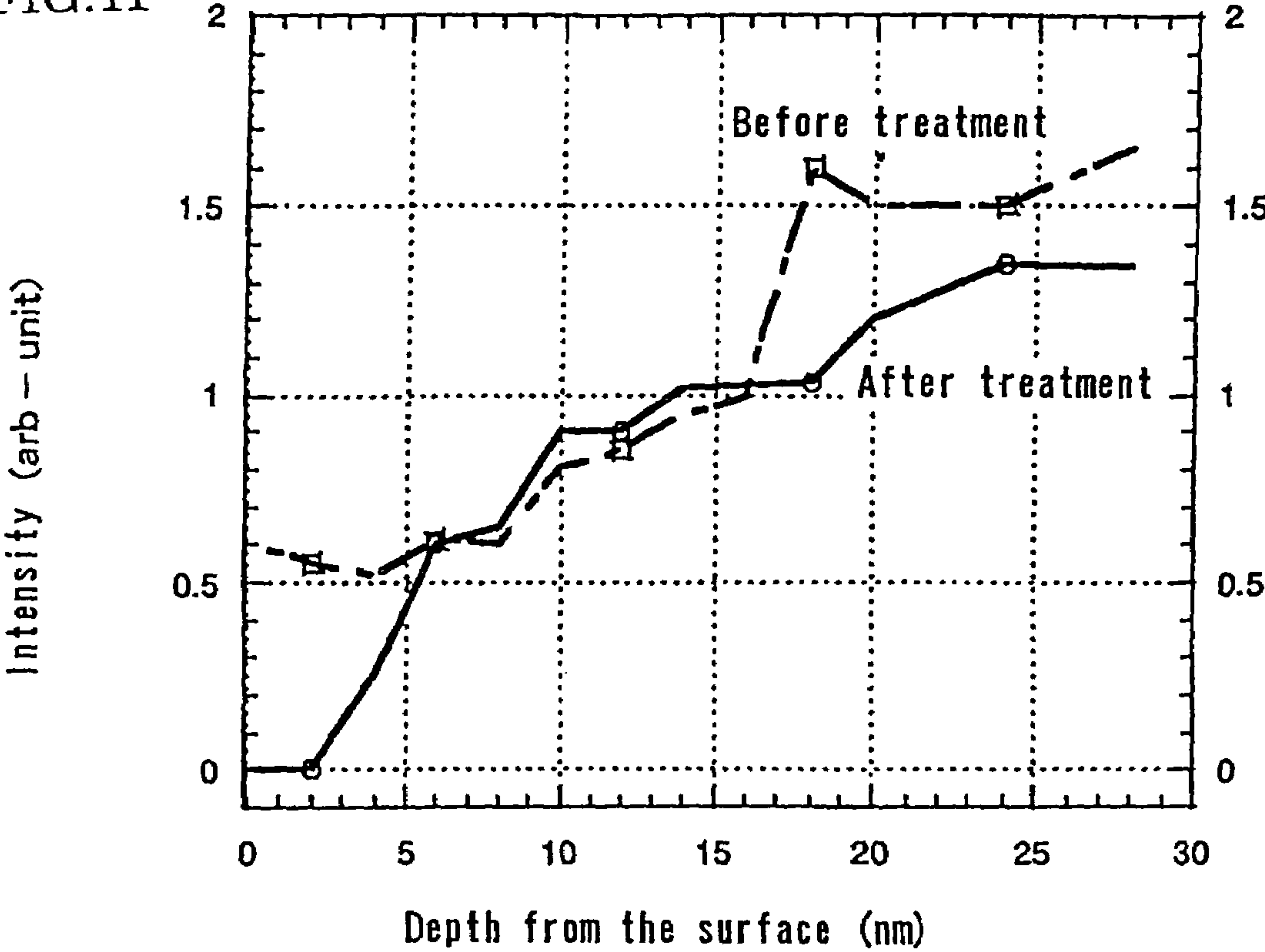
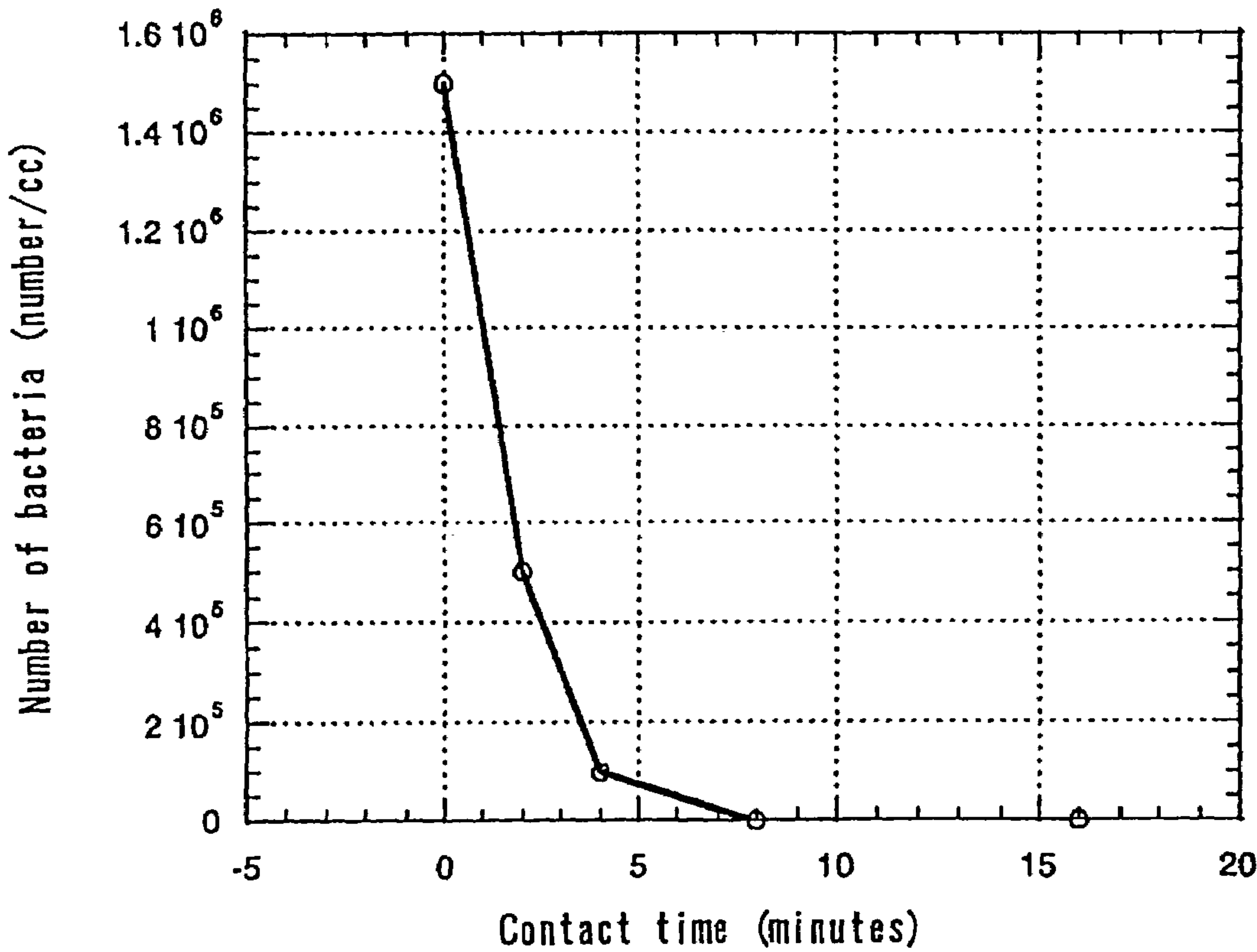


FIG.12



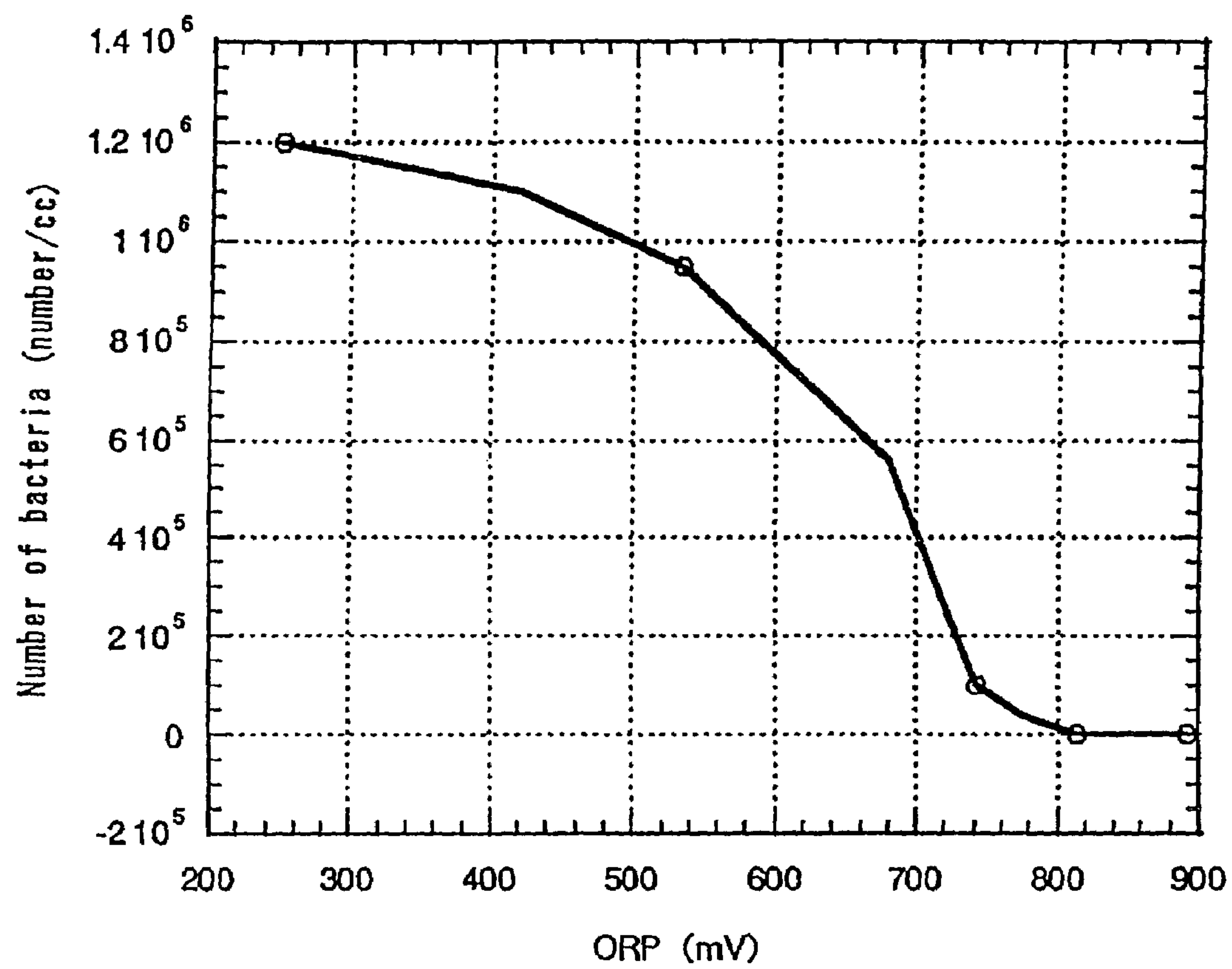


FIG.13

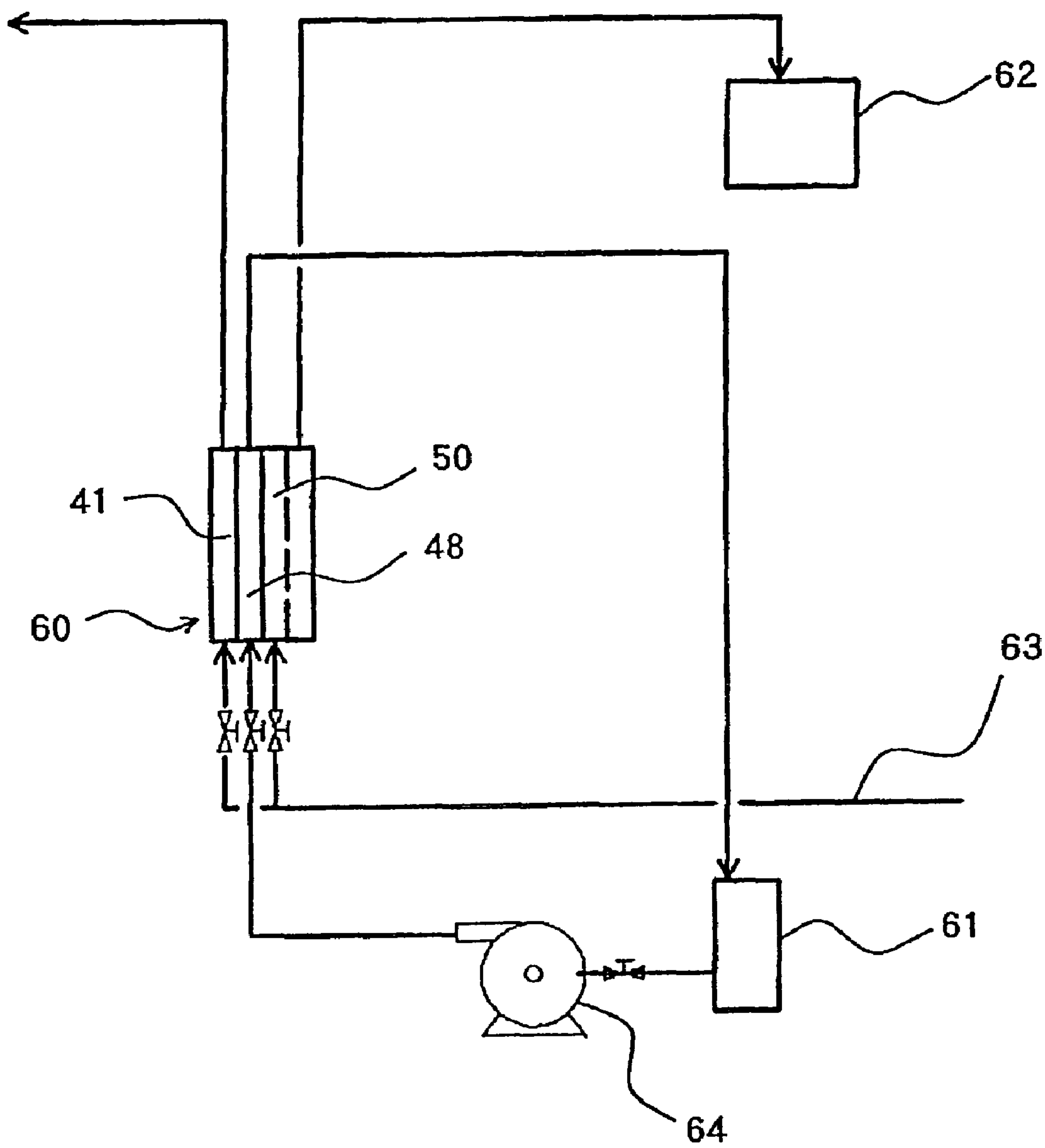


FIG.14

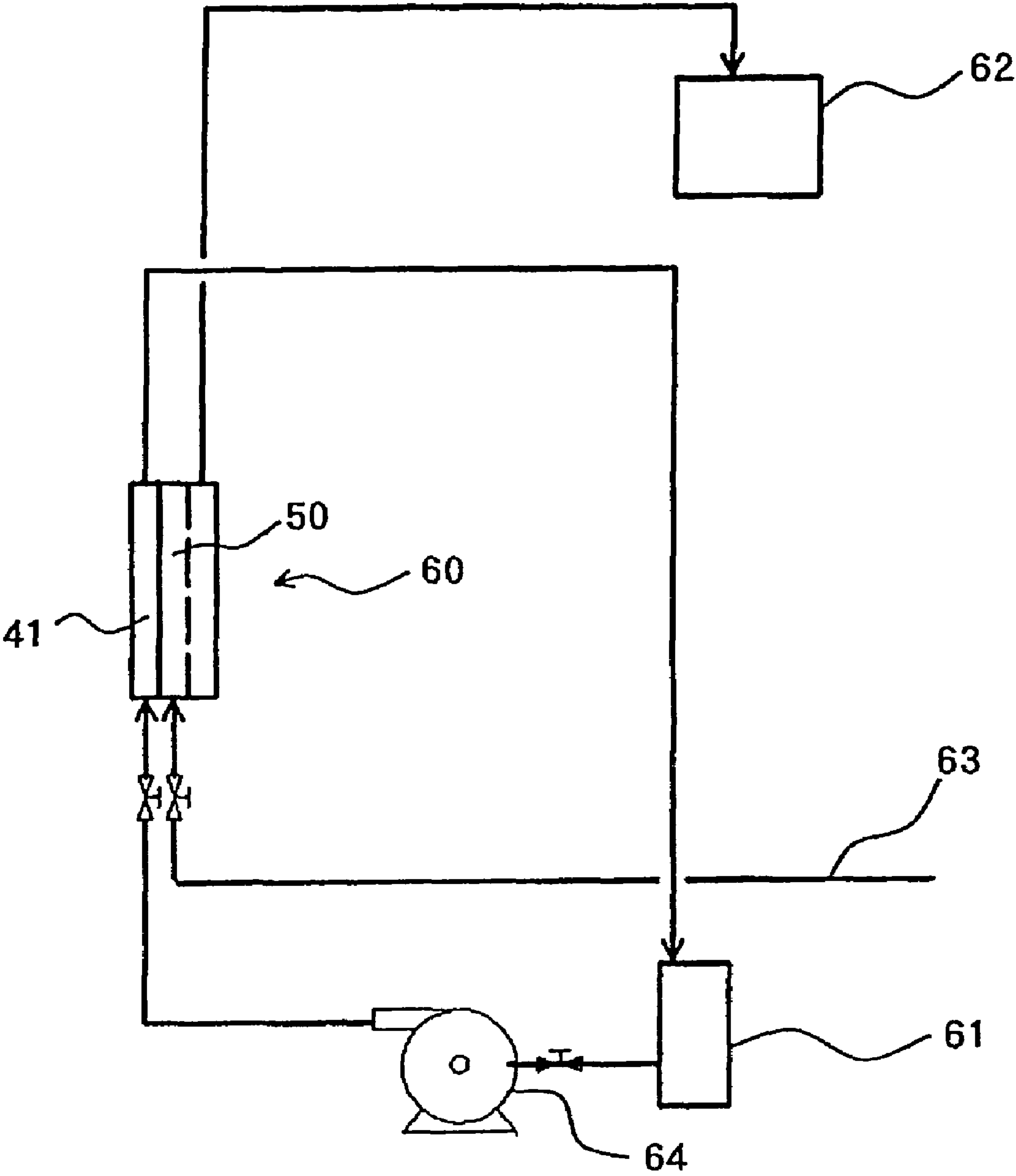


FIG.15

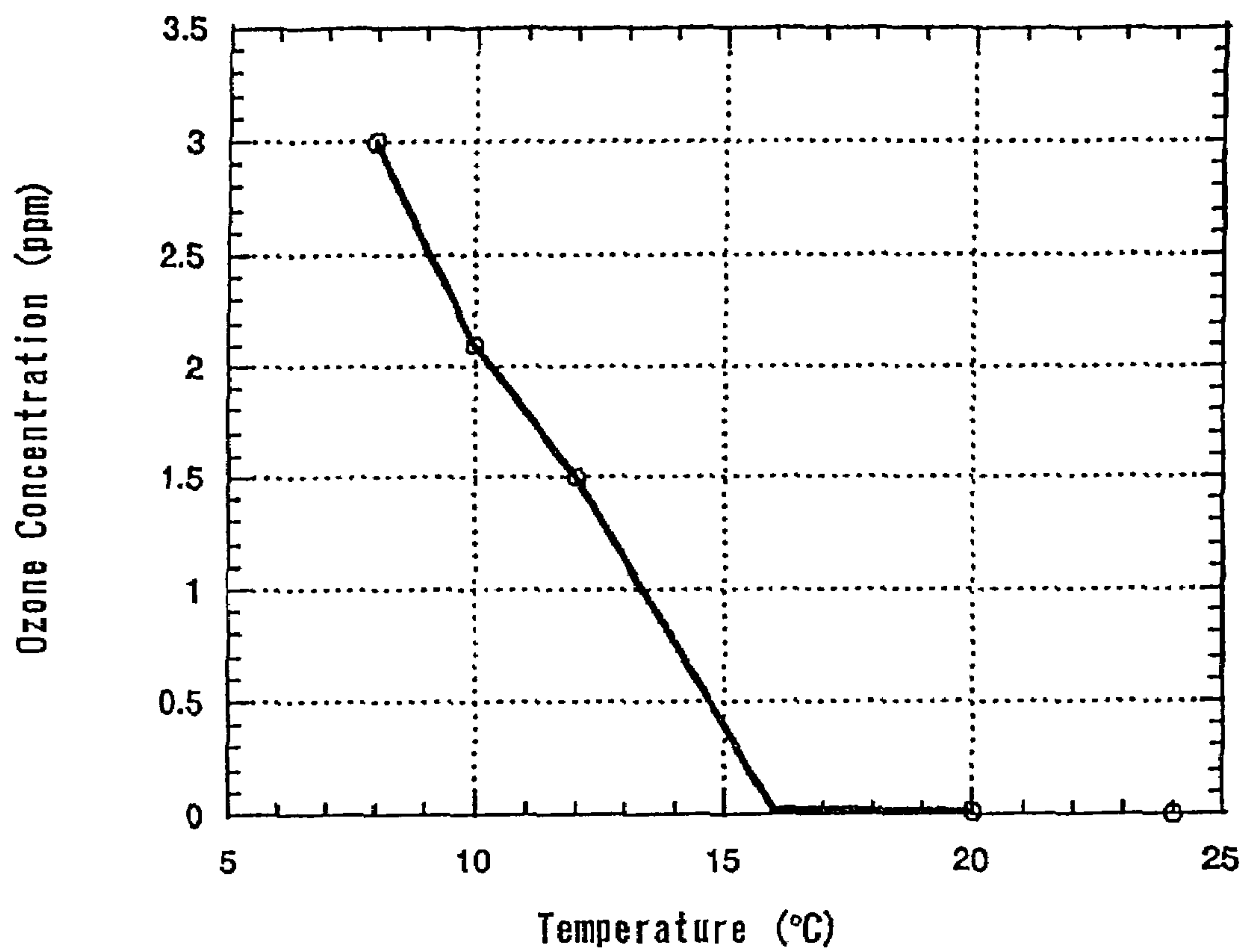


FIG.16

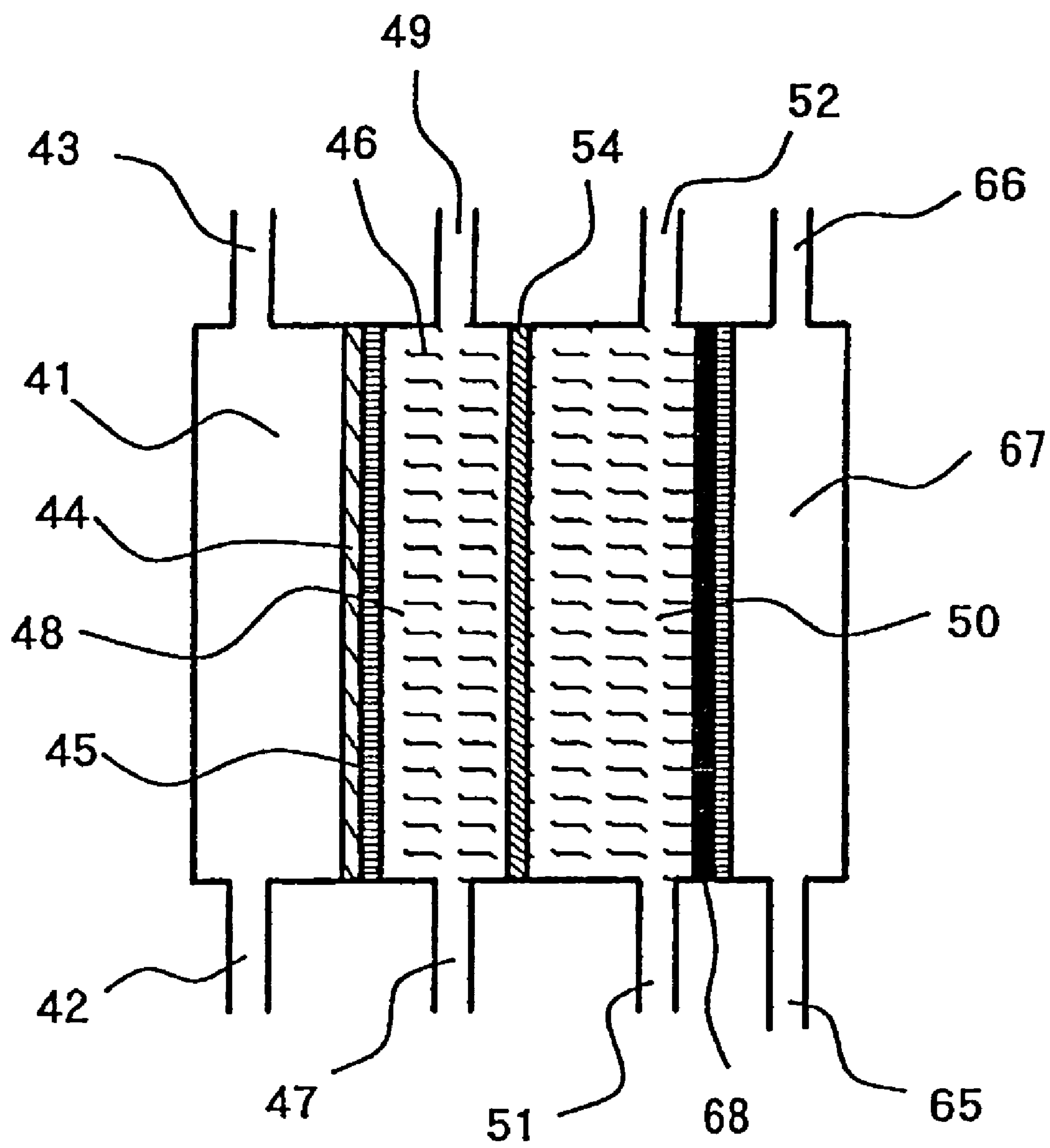


FIG.17

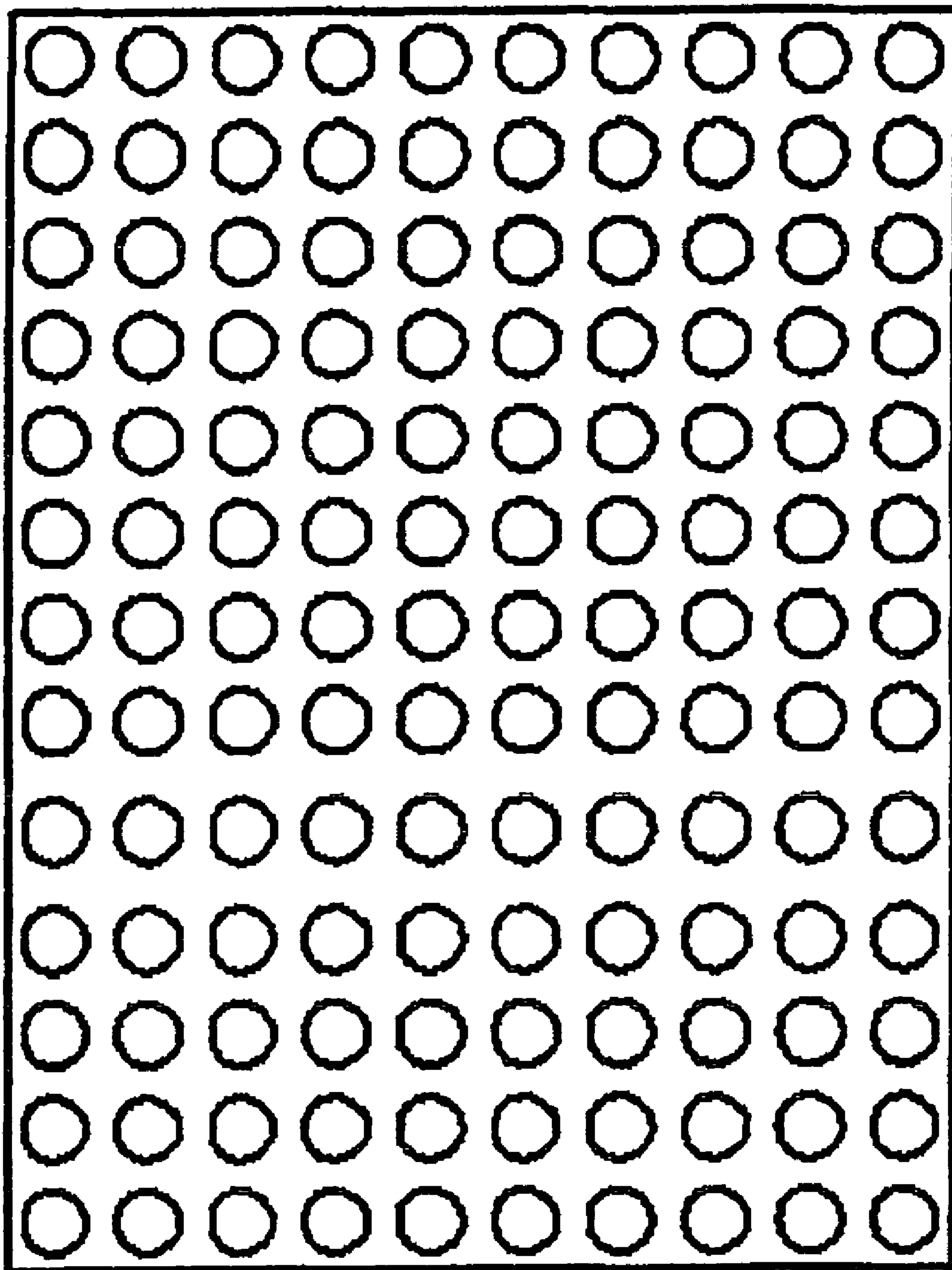


FIG.18

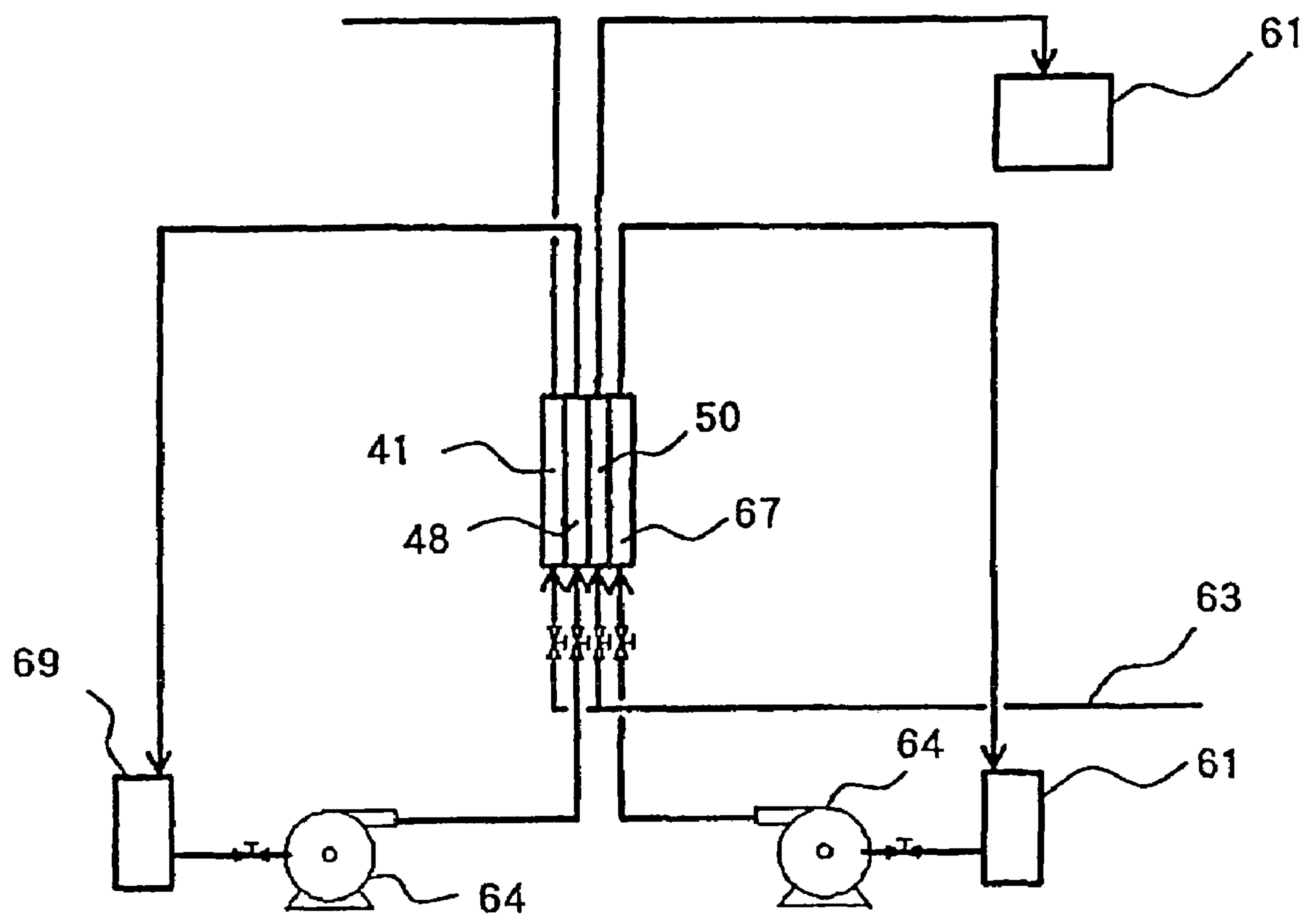


FIG.19

1

ELECTROLYTIC CELL FOR PRODUCING CHARGED ANODE WATER SUITABLE FOR SURFACE CLEANING OR TREATMENT, AND METHOD FOR PRODUCING THE SAME AND USE OF THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application Ser. No. 10/242,779, filed Sep. 13, 2002, now U.S. Pat. No. 7,090,753.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is related to a method for surface cleaning or treatment of semiconductors, glass, or resins, and device for producing electrically charged water as utility water for the above methods, more particularly a technique for providing an electrolysis cell, which can produce electrically charged water suitable for surface cleaning or treatment without using chemical in consideration of environmental protection. The electrically charged water produced by using the electrolysis cell also has antimicrobial activities, and is suitable for cleaning and sterilizing medical devices for which high cleanliness is required.

2. Description of the Related Art

Electrolysis cell using ion exchange membrane, as shown FIG. 1, facilitates the electrolysis of water with low conductivity such as RO water treated using a reverse osmosis membrane pure water, and ultra pure water. In this cell, a fluorinated cation exchange membrane 5 is usually used.

And then an anode electrode 4 in the anode cell 1 and a cathode electrode 9 in the cathode cell 6 are closely attached to the membrane 5. The notation 2 denotes the anode chamber inlet, 3 denotes anode chamber outlet, 7 denotes the cathode chamber inlet, and 8 denotes the cathode chamber outlet.

The ion exchange group in fluorinated cation exchange membrane 5 shown in FIG. 1 is known to enhance the dissociation even in the pure water according to the reaction (1).



The dissociated hydrogen ions increase the electro conductivity of pure water, which contains no impurities, and then decrease the electrolysis voltage.

Next, the reaction (2) and (3) proceed when pure water is electrolyzed using the cell shown in FIG. 1.

At anode



At cathode



These reactions increase the oxygen concentration in the anode solution and the hydrogen concentration in the cathode solution, while leaving the essential properties of electrolytic water unchanged.

In other words, the charged water produced using electrolysis cell shown in FIG. 1 may not be suitable for the surface cleaning or treatment of semiconductors, glass, or resins.

In order to enhance the cleaning or surface treatment efficacy, anode water is required to be more oxidative and/or acidic and cathode water is required to be more reductive and/or alkaline. However, the electrolysis cell shown in FIG. 1 is difficult to produce the effective solutions.

2

For example, the oxidation and reduction potential (hereinafter abbreviated as ORP) of anode water is from 200 to 300 mV (vs., Ag/AgCl) and pH is around neutral: the ORP of normal pure water is around 200 mV.

The three-chamber cell shown in FIG. 2 is designed to solve the problem mentioned above, where the middle chamber 111 is added between the anode chamber 11 and the cathode chamber. 16. Using the three-chamber cell easily electrolyzes pure water or ultra pure water.

Referring to FIG. 2, the three-chamber cell has the chamber 11 and 111 separated by the ion exchange membrane 151, chamber 16 and 111 separated by the ion exchange membrane 152, the middle chamber 111 filled with ion exchange resins as a solid electrolyte, the middle chamber inlet 112 and outlet 113, cathode 19 and anode 14 provided in such a way to be closely attached to the ion exchange membrane 151 and 152, respectively, the anode chamber inlet 12 and outlet 13, and the cathode chamber inlet 15 and 17.

The three-chamber cell has the following merits. Reductive species such as dissolved hydrogen gas produced in the cathode chamber 16 are likely to migrate into the anode chamber 11 though the ion exchange membrane 5 when the cell depicted in FIG. 1 is used. However, the middle chamber 111 in the three-chamber cell control the diffusion of reductive species from the cathode chamber 16 to the anode chamber 11 and then the more strongly oxidative anode water can be obtained. In the cell shown in FIG. 2, migration of hydrogen ions formed on the anode 14 toward the cathode 19 is limited, and then the electrolysis reaction (4) takes place in addition to the reaction (3):



This reaction suggests that the pH of cathode water tends to shift to the alkaline region.

In another viewpoint, these phenomena suggest that hydrogen ions formed in the anode chamber 11 in the reaction (1) remain partly in that chamber.

In the three-chamber cell shown in FIG. 2 the anode solution, therefore, is likely to be charged with the hydrogen ions, while the cathode water is charged with hydroxide ions.

Electrochemical analytical methods are suitable for monitoring charges or the like to experimentally confirm the phenomena mentioned above. For example, the changes in measured values can be monitored by a pH sensor equipped with a glass electrode or ORP sensor which measure the oxidation-reduction potential of platinum electrode surface as a standard of a silver/silver chloride electrode. These sensors, following potential changes in the electrodes as the index, are suitable for confirming charges of electrolytic water. A temperature of the electrolytic water is usually kept at from 18 to 24° C. during measurement (the temperature in the following examples was kept at the almost same levels).

SUMMARY OF THE INVENTION

The charged electrolytic water produced using pure water functions as cleaning/surface treatment reagents for semiconductors, liquid crystal glass and hard disk glass or cleaning/sterilizing reagents for medical devices. A decontamination mechanism using electrolytic solutions is simply explained as follows.

Some contaminants are adhered to the surface of the device mentioned above by electrostatic or ionic attractive forces as schematically shown in FIG. 3, where (A) indicates the contaminated surface and (B) indicates the cleaned surface: the surface of substrate is supposed to be positively charged and contaminants are supposed to be negatively charged. When

the contaminated substance is immersed in the effectively charged anode water, the negatively charges on the contaminants surface reacts with excess hydrogen ions in the anode water. Thus the surface charges are partly neutralized to reduce the bonding forces and thereby to facilitate cleaning. Conversely, when the contaminants are positively charged, the negative charges on the contaminated substance surface disappear to reduce the bonding forces. On the other hand, in the case of ionic contaminants, when the contaminated substance is immersed in anode water with excessive hydrogen ions, the anionic contaminants on the surface are likely to dissolve and then migrate to the anode solution to cancel the excessive charge. Using electrolytic water increases thus cleaning efficacy.

Anodic electrolysis of pure water produces the hydrogen ions according to the reaction (2), where no anion is present as counter ion, unlike acidic solutions prepared by adding acid such as hydrochloric acid or sulfuric acid. The anode water produced by electrolyzing pure water exhibits that the solution is charged. Moreover, the hydrogen ion by itself is an electron acceptor and so exhibits one of oxidizing species. So, the oxidation-reduction potential of anode water tends to shift to noble side. In other words, the ORP sensor indicates a plus value.

When the three-chamber cell depicted in FIG. 2 is used, the anode water is not necessarily sufficient for actual cleaning or surface treatment, although the theoretical consideration mentioned above appears to be very promising. So improving the cell is very important to apply to actual use.

More specifically, the important factors for producing effective charged water are an apparent current density (current (A)/apparent area of whole electrode (cm^2), a fluid velocity along the electrode surface, and an true current density (effective current density=current (A)/true area of the electrode (cm^2)). As the fluid velocity increases, the hydrogen ions and other electrolytic species produced on the electrode surface migrate faster to electrolytic water and then strangely charged water can be produced.

The inventors of this invention have found that it is important to pass water not only over the back side of electrode but also over the front side of electrode, based on the study to improve charged water production efficacy.

This result has led to the development of new methods for improving surface cleaning or treatment performance in semiconductors, glass, resins or the like, and of the apparatus (electrolytic cell) of the present invention which can efficiently produce the charged water with an excellent performance described above.

The invention has the following characteristic constituents to achieve the above objects.

(1) An electrolytic cell for producing charged anode water suitable for surface cleaning or treatment, including cathode, middle and anode chambers, a fluorinated cation-exchange membrane provided to separate cathode and middle chambers from each other, A cathode closely attached to the cation-exchange membrane on the side facing the cathode chamber, and a middle chamber filled with fluorinated cation-exchange resins, provided on the other side of the cation-exchange membrane, the cation-exchange resins being arranged in such a way to come into contact with the fluorinated cation-exchange membrane in the cathode chamber side and with the anode in the anode chamber side, wherein the feed water is fed into the middle chamber and passed through the fluorinated cation-exchange resins to be recovered as the charged anode water.

A shape of the fluorinated cation-exchange resin in this invention is not limited. It may be granular or fibrous, the former being more preferable.

The term "surface cleaning" used in this specification means an operation to remove contaminants from the surface and "surface treatment" means an operation to change surface composition or the like of a substance, e.g., glass, having ions, e.g., Na^+ , K^+ , and H^+ , bonded in the bonding network of $\text{Si}-\text{O}$. Phenomena of the migration of Na^+ ions in glass were observed. When Na^+ ions present in the vicinity of the surface are removed, or more specifically ion-exchanged on the surface, the surface is prevented from roughing caused by the Na^+ ions. This process means the surface treatment, which is different form, the removal of foreign particles or impurity ions form the surface.

The ion-exchange membrane is usually cation-exchange membrane, preferably fluorinated cation-exchange membrane. It is essential for the present invention that the anode to be used in combination with the ion-exchange resins (cation-exchange resins) is a porous electrode or electrode having an ineffective area.

(2) The electrolytic cell for producing charged anode water suitable to surface cleaning or treatment according to the invention (1), wherein a porous anode is provided, and the middle chamber has an inlet but no outlet for the feed water to be treated and the anode chamber has an outlet for treated water but no inlet for the feed water.

(3) An electrolytic cell for producing charged anode water for surface cleaning or treatment, including cathode, middle and anode chambers, a fluorinated cation-exchange membrane provided to separate the cathode and middle chambers from each other, cathode closely attached to the cation-exchange membrane on the side facing the cathode chamber, cation exchange resins contained in the middle chamber and arranged to come into contact with the cation-exchange membrane on the opposite side facing the middle chamber another fluorinated cation-exchange resins contained in the compartment between the fluorinated cation exchange membrane and the anode, wherein the feed water is passed over the anode surface and electrolytic water discharged from the anode chamber is recovered as the charged anode water.

(4) The electrolytic cell for producing charged anode water suitable for surface cleaning or treatment according to the invention (3), wherein a cation-exchange membrane is arranged in the middle chamber to divide the chamber into first middle chamber on the cathode chamber side and a second middle chamber on the anode chamber side.

(5) The electrolytic cell for producing charged anode water suitable for surface cleaning or treatment according to one of the inventions (1) to (4), whereon holes in the porous anode have a total area of 10% or more of a whole electrode area.

The holes are preferably arranged evenly on the entire electrode plane. Each hole preferably has an area of 1 mm^2 or more in consideration of passing efficiency of the anode water.

The anode for the present invention preferably has holes having an area 1 mm^2 or more, because a granular cation-exchange resin, when used, tends to pass through the holes, as its diameter is generally 1 mm or so, frequently 2 to 4 mm. However, a porous electrode having a large hole area is serviceable for a resin, e.g., fluorinated cation-exchange resins, which swell in pure water to have a higher friction coefficient between the resin particles. More specifically, DuPont's Nafion NR50 is preferable resin. A fluorinated one is preferable in consideration of resistance of the cation-exchange resin to oxidation reaction. More specifically, Du Pont's Nafion NR50 is preferable resin.

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(6) The electrolytic cell for producing charged anode water suitable for surface cleaning or treatment according to one of the inventions (1) to (4), wherein the electrode has an ineffective area, which has no contribution to electrolysis, of 10% or more of the whole electrode area.

(7) The electrolytic cell for producing charged anode water suitable for surface cleaning or treatment according to one of the inventions (1) to (6), wherein a mechanism of controlling position of the anode in the direction of current flowing towards to cation-exchange resin is provided.

(8) The electrolytic cell for producing charged anode water suitable for surface cleaning or treatment according to one of the inventions (1) to (7), wherein the cation exchange resin is fluorinated one.

(9) A method of using charged anode solution produced by the electrolytic cell according to one of the inventions (1) to (8) for surface cleaning or treatment of an object.

(10) A method using charged anode water produced by the electrolytic cell according to the inventions (1) to (9), wherein feed water is pure water or ultra pure water. Pure water or ultra pure water means water having the resistivity of 0.1M Ω /cm or more.

(11) The method using charged anode water according to the invention (10), wherein the object to be cleaned or treated is a semiconductor, glass, or resin product.

(12) A method using charged anode water according to the invention (10), wherein the object to be cleaned or treated is a medical device.

(13)) A method using charged anode solution produced by the electrolytic cell according to one of the inventions (1) to (9), wherein the feed water to the anode chamber is cooled to increase the ozone concentration in the anode water.

(14) A method using charged anode water produced by the electrolytic cell according to one of the inventions (1) to (4), (6) and (8) to (12), wherein the anode is directly cooled to increase the ozone concentration in the charged anode water.

The porous anode or cathode in each aspect of the present invention described above means that the planar electrode is structured to have holes (hereinafter referred to as "opening") through which water can pass on both front and backside. These openings are preferably arranged in such a way to make resistance to water flow uniform throughout the plane, and normally distributed evenly on the plane. Adequate size of the opening and ratio of the total opening area to the whole planar electrode area changes depending on the current density and resistance to water flow so that the apparatus is required to secure, and are not determined sweepingly.

These factors greatly depend on the electrode hole structure and ion-exchange resin size: increasing opening size and/or ion-exchange resin size decreases the resistance to water flow and, at the same time, increases the effective current density because contact area between the electrode and resins decreases. However, it is difficult to hold the ion-exchange resins between the membrane and electrode, when opening size increases excessively. Therefore, there is an optimum shape for each of opening and ion-exchange resin.

As discussed above, the electrolytic anode water, produced by passing pure water through the electrolysis cell having a controlling function, has the characteristics described in the examples.

BRIEF DESCRIPTION OF THE DRAWING(S)

FIG. 1 shows the schematic cross-sectional view of the conventional electrolytic cell for electrolysis using ion-exchange separator.

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FIG. 2 shows the schematic cross-sectional view of the conventional three-chamber type electrolytic cell.

FIG. 3 describes the decontamination mechanism using the electrolytic water, where (A) describe the situation before treatment and (B) that after treatment.

FIG. 4 shows the schematic cross-sectional view of the electrolytic cell in the first embodiment of the present invention.

FIG. 5 shows the schematic cross-sectional view of the electrolytic cell in the second embodiment of the present invention.

FIG. 6 shows the schematic cross-sectional view of the electrolytic cell in the third embodiment of the present invention.

FIG. 7 shows the influence of the area ratio on pH and ORP values of the electrolytic anode water prepared in the example 1.

FIG. 8 shows the influence of electrolytic current on pH and ORP values of the electrolytic anode water prepared in the example 2.

FIG. 9 shows the influence of the anode position on charging characteristics of the anode water prepared in the example 3.

FIG. 10 shows the relationship between removal rate and cleaning time obtained in the example 4.

FIG. 11 shows the Na^+ ion distribution in the depth direction before and after the treatment, observed in Example 6.

FIG. 12 shows the relationship between the number of bacteria and the contact time with electrolytic anode water prepared in the example 7.

FIG. 13 shows the relationship between the number of bacteria and ORP of the electrolytic anode water prepared in the example 7.

FIG. 14 shows the electrolytic cell system in which a cooler is built.

FIG. 15 shows the electrolytic cell system in which a cooler is built.

FIG. 16 shows the relationship between the ozone concentration and temperature in the middle chamber obtained in the example 8.

FIG. 17 shows the schematic cross-sectional view of the electrolytic cell in which a cooling chamber is built, described in the example 9.

FIG. 18 shows the schematics of a PTFE sheet.

FIG. 19 shows the system diagram of the electrolytic cell in which a cooling chamber is built.

DETAILED DESCRIPTION OF THE REFERRED EMBODIMENTS

The three-chamber type electrolytic cell to which the present invention is applied is described as follows.

Embodiment 1

FIG. 4 illustrates the new three-chamber type electrolytic cell made by improving the conventional three-chamber cell in which the perforated electrode plate shown in the drawing is used.

The anode 53 was closely attached to the cation-exchange membrane before the improvement. Therefore, the electrolytic water flowed along the anode plane, and the electrolysis reaction proceeded between the electrode and ion exchange membrane. As a result, the electrolysis products were formed first between the electrode and ion exchange membrane, and then moved toward the backside of electrode by diffusion or the like.

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In the present invention, on the other hand, the anode is perforated to provide the passages for electrolytic water passing over the electrode surface, in order to utilize the electrolysis product more efficiently. As a result, the electrolytic water flows not only on the electrode surface but also thorough the holes opened in the electrode. The relationship between opening size and ion-exchange resin size is very important. It is necessary to increase the opening size of electrode, in order to water flow rate. However, it is difficult to hold the ion-exchange resins between the membrane and electrode, when the opening size increases excessively as compared with ion-exchange resin size. The ion-exchange resin is either spherical or fibrous, the former being generally more preferable. Its diameter is ranging from around 1 mm when it is small to 2 to 4 mm when it is large. Therefore, an excessively large opening size in comparison with ion-exchange resins is undesirable. The ion-exchange resin preferably has a large diameter to reduce resistance to water flow. Moreover, the fluorinated cation-exchange resin is preferable, because it comes into contact with the anode.

Moreover, the fluorinated cation exchange resins greatly decrease the electrolysis voltage and thus facilitate the electrolysis of pure water. The Nafion NR50 made by Du Pont is preferable fluorinated cation-exchange resin, as mentioned earlier.

It is possible to control the current density by changing the contact area between the fluorinated cation-exchange resin and anode. The fluorinated cation-exchange resin naturally swells in pure water. So its diameter increases with swelling and the swelling increases with temperature. As a result, the contact area between the fluorinated cation-exchange resin and electrode varies with ambient conditions. It is therefore necessary to control the contact area, in order to control the current density.

The electrolytic cell shown in FIG. 4 has a characteristic structure suitable for surface cleaning or treatment. The cell includes the cathode chamber 41, middle chamber 48 and anode chamber 50, fluorinated cation-exchange membrane 45 provided to separate the cathode chamber 41 and middle chamber 48 from each other, cathode 44 closely attached to the cation-exchange membrane 45 on the side facing the cathode chamber 41, cation exchange resin 46 contained in the middle chamber 48 and arranged to come into contact with the cation-exchange membrane 45 on the opposite side facing the middle chamber 48, cation-exchange membrane 54 provided between the middle chamber 48 and anode chamber 50, wherein the feedwater is passed through the anode chamber 50 and the produced electrolytic water discharged from the anode chamber 50 is recovered as the charged anode water. The other components of the electrolytic cell shown in FIG. 4 are the cathode chamber inlet 42, cathode chamber outlet 43, middle chamber inlet 47, middle chamber outlet 49, anode chamber inlet 51 and anode chamber outlet 52.

Embodiment 2

The electrolytic cell shown in FIG. 5 has a characteristic structure in that the feed water flows into the middle chamber 46 and the electrolyzed water discharged from the anode chamber 50 is recovered as the charged anode water. The cell structure as those shown in FIG. 4 are given the same number and their descriptions is omitted.

Embodiment 3

The electrolytic cell structure includes a mechanism to adjust the position of anode 53 in the current flowing direc-

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tion, as shown in FIG. 6. This structure is provided with a frame, outside of the cell, which holds the mobile anode position-adjusting mechanism.

The anode position adjusting mechanism typically is composed of an anode-supporting rod provided with a screw, by which the anode position can be adjusted.

The structure is described in more detail. This structure makes it possible to adjust position of the anode 53, shown in FIG. 4 for embodiment 1, in the current passing direction. More specifically, the anode-supporting rod 58 is set at approximately center of the anode 53 in the current passing direction, held by the holding frame 57 provided in the anode chamber 50 in such a way to be movable in the axial direction, and screwed into the position-adjusting mechanism 56, provided outside of cell, via the O-ring 55 which seals the anode-supporting rod 58. The position can be adjusted by cutting the anode-supporting rod 58 to have male threads and the position-adjusting mechanism 56 to have the corresponding female threads. Position of the anode 53 is adjusted by rotating the position-adjusting mechanism 56 to control the effective electrolysis current. This means the increase in the electrolysis voltage. Detaching the anode 53 from the cathode side improves charging characteristics of the cell.

The same components as those describe in embodiment 1 are given the same numbers and their descriptions are omitted.

EXAMPLE 1

The three-chamber type electrolytic cell shown in FIG. 4 was used, where ultra pure water was supplied to the inlets of the anode chamber 50, middle chamber 48 and cathode chamber 41. The ultra pure water had the following properties:

Resistivity: 18.0 MΩ/cm

Water temperature: 15° C.

Opening diameter: 4φ

Electrode: Platinum plated titanium electrode was used.

Ion-exchange membrane: The membrane 45 was made of a fluorinated cation-exchange membrane (Nafion 117 made by Du Pont).

Ion exchange resin filled in the middle chamber: The middle chamber 48 was filled with a granular fluorinated cation-exchange resin (Nafion NR50 made by Du Pont).

Ion exchange filled in the anode chamber: the room between the anode 53 and membrane 45 was also filled with NR50.

Water flow rate: ultra pure water was passed at 0.75 l/min. through the cathode chamber 41 and anode chamber 50.

The perforated anode 53 assembled in the electrolytic cell used in the example 1 had an apparent area of 48 cm².

The apparent area of the electrode (the openings were two-dimensionally evenly arranged in the Example 1 as follows.

Electrode thickness: 1 mm

Total opening area: 16.23 cm²

Opening ratio: 34%

The ratio of the opening area to the apparent electrode area was changed to obtain the relationship between the ratio and the pH and ORP of charged anode water where the apparent electrolytic current was set at 5 A, as shown in FIG. 7. The electrolysis voltage was very low and around 14 v under this condition. As clear from the figure, measured pH and ORP values, which are characteristic of the anode water, are very sensitive to the area ratio.

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EXAMPLE 2

The effects of electrolytic current on characteristics of anode water were investigated using the same electrolytic cell and ultra pure water as those used in the example 1. FIG. 8 shows the effects of electrolytic current on pH and ORP of the anode water. The charging characteristics such as pH and ORP were improved as the current density was increased.

EXAMPLE 3

The electrolytic cell with adjusting function of anode position shown in FIG. 6 was used to investigate the relationship between the anode electrode position and the charging characteristics such as pH and ORP of anode water, where apparent electrolytic current was set at 4 A. FIG. 9 indicates the result.

The minus position of anode in FIG. 9 indicates that the anode approached towards the cathode side. In order set the electrolytic current at a given level, the electrolytic voltage was decreased, as the anode position was moved toward the cathode side. As the position of anode was moved toward the counter side, the charging characteristics such as pH and ORP were improved. These results show that the effective contact area between the cation exchange resins and anode decreases as the anode is move towards the counter side. The fluorinated ion exchange resin used in the example 3 had rubber like elasticity and was capable of reversibly changing the charging characteristics

EXAMPLE 4

In this example, the anode water was used to confirm the cleaning efficiency. The object to be cleaned was polyethylene plate on which a printing paint (base material was an acrylic resin) containing carbon black was spread. The electrolytic cell was the same one as that used in the example 1, where ultra pure water was supplied to each chamber at the flow rate of 0.75 l/min, and electrolytic current was set at 7 A. The anode water thus produced was run at the same flow rate on the surface of the polyethylene plate for cleaning. FIG. 10 shows the cleaning efficacy, which was defined as the difference between the object weight before and after cleaning divided by the weight before cleaning. For comparison, the ultra pure water without electrolysis was used for cleaning the plate. FIG. 10 indicates that anode solution exhibits a higher cleaning efficacy.

EXAMPLE 5

Next, the effects of anode water on the removal rate of fine particles on silicon wafer were investigated. First, the 8-inch bare wafer was placed on rubber to contaminate with fine particles thereon. The number of fine particles adhered to the wafer surface was ranging from 2,000 to 4,000. Then, The wafer was washed with the electrolytic anode water, which was produced under the same condition as in the example 1, where the electrolytic current was set at 5 A. The electrolytic water was kept in a PFA bottle (20 l), from which the water was run onto the wafer at the flow rate of 3 l/min using a diaphragm pump. The overall schedule is described as follows.

Cleaning with ultra pure water (2 minutes)→cleaning with electrolytic water (3 minutes)→drying by using s spin drier (2 minutes).

The silicon wafer was also cleaned with ultra pure water in place of the electrolytic water for comparison. Table 1 shows the cleaning results.

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TABLE 1

pH	ORP	Removal rate total (%)
6.8	430	31.5
6.5	460	46.3
6.2	510	60.8
5.9	680	89.0
5.5	720	99.5

EXAMPLE 6

In this example, glass substrates for hard disks were treated with electrolytic water.

When a hard disk glass was immersed in the anode water, the surface compositions of hard disk glass were found to change. This glass contained cation such as Na⁺, K⁺, and H⁺, bonded in the bonding network of Si—O.

Sodium ions is known to damage the surface and so desired to remove from surface region to prevent surface roughing. In order to confirm the possibility of ion exchanging effects in anode solution, glass was immersed in the anode water and then the depth profile of cation distribution in a surface layer was measured.

The charged water was produced by using the same electrolytic cell as use in the example 1, where electrolytic current was set at 5 A. The glass was immersed in the charged anode solution for 5 minutes, to observe the surface composition by using an Auger analyzer. FIG. 11 shows the Na⁺ ion distribution in the depth direction before and after immersion. As shown in FIG. 11, immersing the glass in the anode solution decreases the Na⁺ ion concentration in the surface layer.

EXAMPLE 7

The antimicrobial activities of anode water were investigated using the electrolytic cell of present invention. The anode water was produced by using the same cell as used in the example 1, where electrolytic current was set at 8 A. A bacteria containing solution was prepared, where the number of *Escherichia coli* was adjusted to around 10⁷. One part of the bacteria-containing solution was mixed with 30 parts of the anode solution. The mixture, stirred for a give time, was spread on the standard agar culture medium to culture the bacteria at 30° C. for 24 hours and the number of the bacteria was countered. FIG. 12 shows the relationship between the number of bacteria and the contact time with the anode water. FIG. 13 sows the sterilization effect of the anode water, where the number of bacteria is plotted against ORP of the water. FIGS. 12 and 13 indicates that the anode water exhibits the sterilization effect when the ORP level exceed 800 mV.

EXAMPLE 8

Oxidation capacity of the anode solution produced by an electrolytic cell is also very sensitive to electrolysis temperature. As the temperature decreases, the ozone production efficacy increases and then the oxidation capacity increases. Cooling is a good method for decreasing the temperature in the electrolytic cell. The cooling system depicted in FIGS. 14 and 15 can keep temperature of water in a middle chamber or cathode chamber at low level, to improve ozone production efficiency. FIG. 16 shows that the ozone production efficiency changes with temperate in electrolytic cell used in the example 1 with the cooling system shown in FIG. 14. In FIGS. 14 and 15, same components as those described in

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embodiments are given the same numbers and their descriptions are omitted. The other components are the three-chamber type electrolytic cell **60**, cooler **61**, anode electrolytic water tank **62**, feed water line **63** and pump **64**.

EXAMPLE 9

The example 9 describes another cooling method. As depicted in FIG. **17**, the anode chamber is divided into the chamber through which the anode water flows and the other chamber through which cooling water flows. In FIG. **17**, the same components as those described in the embodiment 1 are given the same numbers and their descriptions are omitted. The other components are the cooling chamber inlet **66**, cooling chamber outlet **65**, cooling chamber **67** and baffle **68**.

In this case, the anode was not provided with openings. However, a perforated PTFE (fluorocarbon resin) shown in FIG. **18** was placed on a surface of the anode of platinum-plated titanium, 80 by 60 mm, to increase effective current density on the anode. In this example, the PTFE sheet, 60 by 80 mm, was provided with openings of 4 mm in diameter, as shown in FIG. **18**.

Temperature in the electrolytic cell was controlled by the system shown in FIG. **19**, which passed cooling water to cooling chamber to directly cool the anode. In FIG. **19**, the same components as those described in the embodiment are omitted. The other components include the liquid tank **69** in the middle chamber. Keeping temperature in the electrolytic cell at a low level by using the cooler improved ozone production efficiency, as described in the example 8.

The electrolytic cell of the present invention can produce strongly charged anode water. Moreover, It can improve ozone production efficiency, when its anode is cooled. The charged water produced by the electrolytic cell is effective for cleaning a silicon wafer by removing fine particles or the like wherefrom or glass surface treatment for promoting ion exchanging on the surface to prevent surface roughing. It is also effective for cleaning resins or the like, in particular resins for medical devices. For Example, it is effective for cleaning and sterilizing the inner surfaces of catheters or like. No special chemical remains after cleaning, which is its advantage.

The invention claimed is:

1. A method of preparing charged anode water, the method comprising the steps of:

- (a) feeding feed water into the middle chamber of a electrolytic cell comprising a cathode chamber, a middle chamber, and an anode chamber, a fluorinated cation-exchange membrane separating the cathode chamber and the middle chamber from each other, a cathode closely attached to a cation-exchange membrane on the side facing the cathode chamber, wherein the middle chamber is filled with cation-exchange resins, wherein the cation-exchange resins are arranged in such a way to come into contact with the fluorinated cation-exchange membrane in the cathode chamber side and with an anode in the anode chamber side,
- (b) passing the feed water through the cation-exchange resins, and

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(c) recovering the charged anode water from the anode chamber.

2. The method of claim **1**, wherein the anode is porous.

3. The method of claim **2**, wherein the anode comprises an electrode with holes having a total area of 10% or more of the whole electrode area.

4. The method of claim **1**, wherein the anode comprises an electrode with an ineffective area having no contribution to electrolysis of 10% or more of the whole electrode area.

5. The method of claim **1**, further comprising a mechanism of controlling the position of the anode in the direction of current passing towards the cation-exchange resins.

6. The method of claim **1**, wherein the cation-exchange resins are fluorinated.

7. The method of claim **1**, further comprising cooling the anode.

8. A method of preparing charged anode water, the method comprising the steps of:

- (a) feeding feed water into the middle chamber of a electrolytic cell comprising a cathode chamber, a middle chamber, and an anode chamber, a first fluorinated cation-exchange membrane provided to separate the cathode chamber and the middle chamber from each other, a cathode closely attached to the fluorinated cation-exchange membrane on the side facing the cathode chamber, cation exchange resins contained in the middle chamber and arranged to come into contact with the cation-exchange membrane on the opposite side facing the middle chamber, a second fluorinated cation-exchange membrane provided between the middle chamber and the anode chamber, wherein fluorinated cation-exchange resins are contained in the space between the second fluorinated cation-exchange membrane and an anode,

(b) passing the feed water through the cation-exchange resins, and

(c) recovering the charged anode water from the anode chamber.

9. The method of claim **8**, wherein a third fluorinated cation-exchange membrane is arranged in the middle chamber to divide the chamber into a first middle chamber on the cathode chamber side and a second middle chamber on the anode chamber side.

10. The method of claim **8**, wherein the anode is porous.

11. The method of claim **10**, wherein the anode comprises an electrode with holes having a total area of 10% or more of the whole electrode area.

12. The method of claim **8**, wherein the anode comprises an electrode with an ineffective area having no contribution to electrolysis of 10% or more of the whole electrode area.

13. The method of claim **8**, further comprising a mechanism of controlling the position of the anode in the direction of current passing towards the cation-exchange resins.

14. The method of claim **8**, wherein the cation-exchange resins are fluorinated.

15. The method of claim **8**, further comprising cooling the anode.

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